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LOWER LIMB ASYMMETRIES IN RHYTHMIC GYMNASTICS ATHLETES

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ABSTRACT

Background: Different limb training demands and limb preference may determine anthropometric and muscle force inter-limb asymmetries in Rhythmic Gymnastics (RG) athletes.

Purpose: The purpose of this study was to evaluate the influence of lateral preference of the lower extremity on anthropometric, range of motion, and isokinetic torque measurements of RG athletes.

Study Design: Cross sectional study

Methods: Lower limb anthropometric measurements (girth, estimated anatomical cross-sectional area), hip, knee and ankle range of motion, flexor and extensor isokinetic torques (angular velocities = 60, 180, e $240^\circ \cdot s^{-1}$) and bilateral asymmetry index were evaluated in 11 international level Rhythmic Gymnastics athletes (17.9 ± 4.0 years of age; 9.1 ± 5,1 years of experience; 26.8 ± 6.0 weekly training hours).

Results: The preferred limb showed larger thigh girth and anatomical cross-sectional area, higher ankle dorsiflexor range of motion, higher hip flexor torque at $60^\circ \cdot s^{-1}$ and higher plantarflexor torque at $180^\circ \cdot s^{-1}$ compared to the non-preferred limb.

Conclusions: The observed differences seem to be strictly related to lateral preference and rhythmic gymnastics training.

Levels of Evidence: **3**

Keywords: Ankle joint; hip joint; isokinetic dynamometer; knee joint; muscle strength.

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INTRODUCTION

Aesthetic movements and flexibility are distinct characteristics of Rhythmic Gymnastics (RG). This unique sport encompasses both artistic and competitive characteristics. At the artistic level, talent and creativity are evident through both motor control and movement harmony. With regard to the competitive aspect, this female sport requires a high degree of physical, technical and psychological skills aimed at obtaining a perfect execution of the corporal movements with the different types of equipment (ball, ribbon, hoop, clubs, rope).[1]

In order to achieve the necessary preparation for a good performance, high-performance gymnasts train on average 25-30 weekly hours and, in some cases, 40 weekly hours due to the high technical demands of this sport modality.[2,3] These high technical demands, in turn, increase the athletes' physical demands. According to Douda et al,[4] the prolonged training time required of these athletes might induce structural changes in the gymnasts' motion system. These authors demonstrated that juvenile and adult RG athletes with the highest training time presented with asymmetries of lower limb girth due to the prevalence of exercises performed on the preferred side.

This preference for one side might cause bilateral differences in torque output, similar to those that have been shown in athletes of other sports such as soccer, where although the non-preferred side also participates in the sports activities the use of the preferred side is prioritized. The use of preferred side is not exclusive in the execution of the majority of the technical gestures[5,6] and bilateral torque asymmetry is accepted as being normal up to a 10% level.[6]

Based on the training volume, the presence of lateral preference and its influence on the structural and functional adaptation of RG athletes, it was hypothesized that bilateral differences would exist in the anthropometric, range of motion, and torque measurements, favoring the preferred side over the non-preferred side. Very few studies have examined this issue and there is a lack of studies examining sports performance in RG. Most studies have examined sexual maturation, eating disorders and corporal image distortion.[7,8] Therefore, the purpose of this study was to evaluate the influence of lateral preference of the lower limb on anthropometric, range of motion, and isokinetic torque measurements of RG athletes.

METHODS

This study was approved by the Federal University of Santa Catarina Human Ethics in Research Committee (370.108). Eleven RG international level athletes from a Brazilian Sports Club signed an informed consent form agreeing to participate in the study. Informed consent of athletes under the age of 18 years old was given by their parents. Athletes were 17.9 (± 4.0) years old, and were 1.63 (± 0.07) meters tall, had body mass of 51.2 (± 7.2) kg, a body mass index of 19.3 (± 1.8) kg/m^2 and had been practicing RG for 9.1 (± 5.1) years. Athletes practiced for an average of 26.8 (± 6.0) weekly training hours, and the athletes included South American gold medalists, Pan-American gold medalists, and one Olympic finalist.

Lateral preference was determined by the Waterloo - WFQ-R questionnaire[9]. Five other questions used by Goulart,[10] related to specific RG activities, were incorporated in the evaluation. Before the beginning of any physical effort, mid-thigh girth, leg girth (calf maximum girth), skinfold (front thigh and medial calf skinfold site), femur biepicondyle diameter and passive range of motion for hip flexion, hip extension, knee flexion, knee extension, ankle plantar flexion and ankle dorsiflexion were determined bilaterally.

The thigh anthropometric measurements were used to estimate the thigh anatomical cross-sectional area (ACSA) using equation 1:[11]

$$\text{ACSA} = 0.649 \times (\text{TC}/\pi - \text{TSF})^2 - (0.3 \times \text{FBD})^2$$

where ACSA represents the thigh cross-sectional area, TC the thigh circumference, TSF the thigh skinfold and FBD the femoral biepicondyle diameter.

Joint range of motion was determined according to the movement patterns described on the Flexitest[12] (Dr. Claudio Gil Soares de Araujo, São Paulo, Brazil). The Flexitest is a method for measurement and evaluation of the passive mobility of 20 joint movements in which each movement is quantified in an ordinal scale from 0 to 4. The method allows the examiner to obtain a global flexibility index and to perform specific and isolated analysis of different movements and joints.[12] In the present study, the Flexitest isolated analysis was used by passively moving the hip and knee into flexion and extension and the ankle into plantar flexion and dorsiflexion. These movement patterns were recorded with a digital camera, and the joint angles were obtained from the video analysis of these movements. Anatomical markers (12 mm of diameter), a 12.1 megapixel digital camera (Sony Cyber-shot DSC - W310, Tokyo, Japan) and a leveled tripod (Vivitar – VPT 1200, Sakar International, Inc., New Jersey, USA) were used to determine angular measurements by photogrammetry method.[13]

For the range of motion measurements, the anatomical position was considered as zero degrees for all joints. The anatomical markers were placed at the bony protuberances of each joint and were replaced whenever necessary at each of the positions to minimize the changes caused by skin movement. For hip flexion and extension the femur greater trochanter was regarded as the central joint axis of motion. Angles were obtained from straight lines formed between (1) the vertex and the femoral condyle of the tested leg, which was conducted to carry out the movement, and (2) to the ankle medial malleolus of the opposite leg, which remained in contact with the ground. For knee flexion and extension the knee femoral condyle was regarded as the center of motion, and the angles were obtained between the lines (1) from the lateral malleolus to the femoral condyle and (2) the femur greater trochanter to the femoral condyle of the tested lower limb. For ankle dorsi and plantar flexion, the lateral malleolus was considered the center of motion and the angles were obtained between the lines (1) from the fifth toe (tip) to the lateral malleolus and from (2) the lateral tibial condyle of the tested lower limb. Kinovea 0.8.15 (Joan Charmant & Contrib. Bordeaux, France) software was used to determine angular joint measurements.

Peak torque values were obtained for the hip (flexion-extension), knee (flexion-extension) and ankle (plantar-dorsiflexion) joints using an isokinetic dynamometer (Biodex System 4 Pro, Biodex Medical Systems, New York, USA). A five-minute warmup was executed on a cycle-ergometer (Ergocycle 167 Cardio, Ergo-fit GmbH & Co. KG, Pirmasens, Germany), with 25 W of load before the tests. After the warmup period, the athletes executed a familiarization session with the dynamometer, consisting of five submaximal voluntary concentric contractions at the angular velocities of $60^\circ \cdot s^{-1}$ and $240^\circ \cdot s^{-1}$.

The torque testing protocol consisted of five maximal voluntary concentric contractions at the angular velocities of $60^\circ \cdot s^{-1}$, $180^\circ \cdot s^{-1}$ and $240^\circ \cdot s^{-1}$ with a random order between velocities and between joints. A 90 second rest interval was observed between angular velocities to avoid possible fatigue effects. For all joints, at the end of the test, the first angular velocity performed was repeated in order to assess for fatigue. Paired t-tests were used to evaluate differences between the first maximal voluntary contraction and its repetition and no differences were found. All subjects received verbal encouragement in order to obtain their maximal performance on each test.

The angular velocities of $60^\circ \cdot s^{-1}$, $180^\circ \cdot s^{-1}$ and $240^\circ \cdot s^{-1}$ were chosen for being a slow, an intermediate, and a fast angular velocity, respectively. The $60^\circ \cdot s^{-1}$ angular velocity has been widely used in different studies to determine maximal peak torque and work, whereas angular velocities of $180^\circ \cdot s^{-1}$ and higher have been used to determine muscle power, with $180^\circ \cdot s^{-1}$ being the angular velocity where peak power was observed in women, during knee extension.[14]

Absolute torque values were determined by normalizing to the body mass for each athlete in order to minimize possible anthropometric effects on maximal torque production.[15] A 10% bilateral difference was established as the maximum value for a normal difference (i.e. no asymmetry) between the preferred and non-preferred sides[6]. The asymmetry index (AI) was calculated using equation 2:[16]

$$AI\% = \left(\frac{P - NP}{P}\right) \times 100 \qquad (2)$$

where AI represents the asymmetry index, P is the preferred side and NP the non-preferred side.

Statistical Methods

Statistical analysis was performed using SPSS 15.0 for Windows Software. Paired t-tests were used to evaluate between preferred and non-preferred differences in anthropometric and torque values. The

Pearson correlation test was used to evaluate the relation between torque and the characterization variables (age, height, weight, years of training, hours of training per week, pubertal status) and between torque and the anthropometric variables (girth values, cross-sectional area and range of motion). For variables that showed high correlation values (above 0.7) a simple linear regression was used to evaluate the functional relation of variables on torque. A level of significance of $p < 0.05$ was adopted for all tests.

RESULTS

The Waterloo Questionnaire revealed the right lower limb as the preferred limb for all athletes. While the right limb was used for manipulation tasks, the left (non-preferred) side was used by the majority for weight bearing and balance.

The anthropometric evaluation revealed higher thigh cross-sectional area and girth for the preferred limb compared to the non-preferred limb (Table 1). There were no differences between limbs for joint range of motion at the hip, knee and ankle, except for dorsiflexion that was higher at the preferred side compared to the non-preferred side.

There was no difference for the normalized torque between the preferred and the non-preferred limbs, except for the hip flexion at $60^{\circ} \cdot s^{-1}$ and for the plantarflexion at $180^{\circ} \cdot s^{-1}$ that were higher in the preferred compared to the non-preferred limb (Table 2). No fatigue was observed during the protocol, as no difference was observed between the first and the last repetitions at the same angular velocity (results not shown).

The asymmetry index also revealed no difference between the preferred and non-preferred limbs for the different angular velocities and joint motions. Asymmetries were observed only for ankle plantiflexion at $180^{\circ} \cdot s^{-1}$ and for ankle dorsiflexion at $240^{\circ} \cdot s^{-1}$ in favor of the preferred limb (Table 3).

Table 1. *Anthropometric measurements and joint range of motion for the preferred (PREF) and non-preferred (NPREF) sides of the Rhythmic Gymnastics athletes. Values are expressed as mean and SD.*

PARAMETERS	SEGMENT	PREF	NPREF
Girth (cm)	**Thigh**	45.2 ± 3.0*	44.5 ± 2.9
	Leg	33.2 ± 2.3	33.4 ± 2.1
Skin fold (cm)	**Thigh**	1.41 ± 0.5	1.40 ± 0.6
	Leg	1.0 ± 0.5	1.0 ± 0.4
Bone Diameter (cm)	**Biepicondilar femur**	7.1 ± 0.4	7.1 ± 0.4
CSA (cm²)	**Thigh**	106.8 ± 12.4*	102.7 ± 11.8
ROM FLX (degrees)	**Hip**	141.8 ± 9.5	138.3 ± 5.4
ROM EXT (degrees)		44.0 ± 17.2	44.8 ± 19.0
ROM FLX (degrees)	**Knee**	151.8 ± 7.0	151.3 ± 7.4
ROM EXT (degrees)		-8.1 ± 5.2	-8.4 ± 5.1
ROM PLANTI (degrees)	**Ankle**	86.9 ± 7.1	88.4 ± 7.9
ROM DORSI (degrees)		25.9 ± 7.4*	21.7 ± 8.8

CSA = Cross-Sectional Area; ROM = Range of Motion; FLX = Flexion; EXT = Extension; PLANTI = Plantarflexion; DORSI = Dorsiflexion.

* indicates (p<0.05) with the preferred > non-preferred side.

Table 2. *Peak torque normalized to body mass (mean ± SD) at the different angular velocities for the different joints of the preferred and non-preferred limb.*

TORQUE ($N \cdot m \cdot kg^{-1}$)		HIP		KNEE		ANKLE	
ANG VEL	Movement	PREF	NPREF	PREF	NPREF	PREF	NPREF
$60° \cdot s^{-1}$	FLX/PLANTI	1.3 ± 0.3*	1.2 ± 0.4	1.4 ± 0.3	1.4 ± 0.2	1.2 ± 0.3	1.1 ± 0.3
	EXT/DORSI	3.3 ± 0.5	3.0 ± 0.4	2.0 ± 0.4	2.1 ± 0.3	0.2 ± 0.1	0.2 ± 0.1
$180° \cdot s^{-1}$	FLX/PLANTI	0.9 ± 0.4	0.9 ± 0.4	1.2 ± 0.3	1.2 ± 0.3	0.7 ± 0.2*	0.6 ± 0.3
	EXT/DORSI	2.6 ± 0.4	2.5 ± 0.3	1.4 ± 0.2	1.4 ± 0.2	0.1 ± 0.1	0.1 ± 0.1
$240° \cdot s^{-1}$	FLX/PLANTI	0.8 ± 0.4	0.8 ± 0.4	1.2 ± 0.2	1.2 ± 0.2	0.6 ± 0.2	0.6 ± 0.2
	EXT/DORSI	2.6 ± 0.5	2.4 ± 0.5	1.3 ± 0.2	1.3 ± 0.2	0.1 ± 0.1	0.1 ± 0.1

* = p<0.05; ANG VEL = Angular Velocity; PREF = Preferred limb; NPREF = Non-Preferred limb; FLX = Flexion; EXT = Extension; PLANTI = Plantarflexion; DORSI = Dorsiflexion.

Table 3. *Asymmetry index (mean ± SD) for the hip, knee and ankle joints at the different angular velocities and joint motions.*

	HIP		KNEE		ANKLE	
	FLX (%)	EXT (%)	FLX (%)	EXT (%)	PLANTI (%)	DORSI (%)
$60° \cdot s^{-1}$	9.8 ± 12.0	8.5 ± 15.4	-1.4 ± 9.2	-4.6 ± 12.0	4.1 ± 13.9	-0.9 ± 15.9
$180° \cdot s^{-1}$	3.8 ± 24.4	3.1 ± 12.7	-1.5 ± 7.0	-1.2 ± 8.5	12.9 ± 14.8*	4.1 ± 38.5
$240° \cdot s^{-1}$	-1.8 ± 36.3	6.3 ± 16.3	-5.0 ± 10.7	0.3 ± 10.8	7.2 ± 19.4	13.2 ± 38.8*

* indicates p<0.05. Positive values represent asymmetries in favor of the preferred limb, whereas negative values for the non-preferred limb. FLX = Flexion; EXT = Extension; PLANTI = Plantarflexion; DORSI = Dorsiflexion.

No strong correlations were observed between torque and the characterization variables (age, height, weight, years of training, hours of training per week and pubertal status). Similarly, no strong correlations were observed between hip torque values and range of motion, cross-sectional area and other anthropometric variables. Strong, statistically significant correlations were observed for knee joint range of motion during flexion and knee extensor torque at $60° \cdot s^{-1}$ for both limbs (preferred: p = 0.011; r = 0.728; non-preferred: p = 0.014; r = 0.711) and for knee extensor torque at $240° \cdot s^{-1}$ in the preferred limb (p = 0.007; r = 0.759).

The linear regression test showed a determination coefficient (R^2) of 0.53 between knee extensor torque at $60° \cdot s^{-1}$ of the preferred limb and of 0.51 for the non-preferred limb, which suggests that, on both sides, more than 50% of the torque values were influenced by knee flexion range of motion (preferred = 53%; non preferred = 51%). For knee extensor torque at $240° \cdot s^{-1}$ on the preferred side the determination coefficient was 0.58, with 58% of knee extensor torque related to the joint flexion range of motion.

At the ankle joint, correlation was observed only in the non-preferred limb between dorsiflexor torque values at $240^\circ \cdot s^{-1}$ and the girth values ($p = 0.002$; $r = 0.831$). The linear regression test revealed a determination coefficient of 0.69, indicating that 69% of the torque values were influenced by the leg girth. For all correlation and regression cases the significance level was less than $p = 0.05$.

DISCUSSION

Douda, Laparidis and Tokmakidis[5] have shown that bilateral asymmetry was present for lower limb girth in both the juvenile and adult gymnastics categories, and attributed this asymmetry to the prevalence of exercises performed using the preferred side during training. Based on this idea, the first hypothesis was that the higher use of the preferred limb compared to the non-preferred limb during RG training would determine an increase in bilateral asymmetry both for the anthropometric parameters and for the functional parameters (i.e. joint range of motion, torque). The higher thigh girth and cross-sectional area of the preferred side compared to the non-preferred side partially supported this hypothesis. However, these two higher anatomical measurements of the preferred limb were not accompanied by a higher capacity to generate torque at the hip, knee and ankle joints, where only a few asymmetries were observed. Characterization variables (age, height, weight, years of training, hours of training per week and pubertal status) also showed little evidence of correlation between these variables and functional parameters (joint range of motion and torque). The absence of a relationship between these variables suggests that they do not directly contribute to the observed differences.

One of the characteristics of RG is that athletes need to perform aesthetic movements at high angular velocities. In order to accomplish this, athletes try to maintain a slim body shape, and increase joint angular velocities by increasing muscle contraction velocity. Muscle contraction velocity can be increased by increasing the percentage of fast-twitch fibers and/or by increasing the fascicle length. The authors believe that these athletes increase contraction velocity through the latter, as most of the RG routines involve a large aerobic component and muscles apparently do not show a large increase in cross-sectional area, which is a characteristic of athletes involved in power-based sports. Indeed, RG estimated thigh cross-sectional area and segment girth presented very low values compared to athletes from other sports and to non-athletes.[17] Gómez-Campos et al[18] suggest that RG athletes show reduced muscle areas due to their very intense training regimen. Goulart[12] found an increase in fascicle length of RG athletes compared to non-athletes with similar anthropometric characteristics (height and weight). This supports the idea that RG athletes have long muscles, which helps to increase angular velocity at the joints due to the larger muscle excursion.

The low values observed for thigh girth (preferred: 45.2 cm; non-preferred: 44.5 cm) and thigh CSA (preferred: 106.8 cm^2; non-preferred: 102.7 cm^2) are likely related to the intense training routines and to the athletes' preferred physical presentation in aesthetic sports such as RG, where a slim body favorably displays the specific technical movements.[17,18] These small dimensions in a slim body are apparently accompanied by an increase in muscle fascicle length, but not in muscle cross-sectional area.[10] In a study of athletes involved in classical Ballet, which is highly related to the movements and performance of RG, Golomer et al[19] found no differences in muscle mass and maximal jump height between the preferred and non preferred limbs in professional ballet dancers (mean age = 17.5). The authors suggested that athletes with less developed musculature improved their performances by increasing the duration of the push-off force rather than the magnitude of the peak force.

The estimated cross-sectional area in the athletes in the current study was higher in the preferred compared to the non-preferred limb. The mean cross-sectional difference between limbs (4.08 cm^2) was not related to any increase in strength, as there were no bilateral differences in knee flexor and/or extensor torques. The results of the correlation analysis did not show results indicating the condition of higher torque values to be related to higher muscular areas. Jones et al[20] suggested that differences in force could not be caused solely by increases in muscle cross-sectional area. Another neuromuscular characteristic, such as electrical activation, not evaluated in the present study, may have influenced the present results.

Similar disagreement was observed between the lower leg girth and ankle plantarflexor torque, as no bilateral differences were observed between the preferred and non-preferred limbs girth and the plantarflexor torque was higher on the preferred limb. However, there was a correlation between the non-preferred limb girth and the dorsiflexor torque values at 240°·s^{-1}, with the linear regression model showing an R^2 of 0.69, which suggests that 69% of the dorsiflexor torque at 240°·s^{-1} was influenced by the variation in leg girth. It is speculated that this relation between the leg girth and dorsiflexors torque values at 240°·s^{-1} of the non-preferred limb results from the systematic cocontraction of this musculature in order to increase ankle and foot stability during powerful movements.[21,22] The tibialis anterior muscle has the important role of stabilizing foot inversion-eversion during jumps and during the point and demi point (half-tiptoe/forefoot) movements.

Another factor that might be related to the present findings is the fact that in the majority of the jumps in RG, such as the split leap, the non-preferred leg acts as the propulsion leg. One of the strategies that benefits performance of these jumps is the countermovement produced by the ankle dorsiflexion and consequent solicitation of the dorsiflexor muscles.[23] The gymnast will leap with her right leg forward (PREF) and use her left leg (NPREF) as the propulsion leg. This propulsion requires significant, rapid, kinetic force generation from the left leg (NPREF) to propel the gymnast's body upwards and forwards.

Although muscle length was not tested, greater range of motion may be associated with greater muscle length. Muscles with longer fascicles affect force production due to the larger number of serial sarcomeres and larger muscle excursion.[24,25] The larger dorsiflexor range of motion on the preferred limb, that may associated with larger sarcomere numbers, could lead to a greater shortening velocity[10,26,27] that might explain the differences found during the isokinetic tests at the angular velocity of 180°·s^{-1}, where the preferred limb produced higher torque values compared to the non-preferred side during plantarflexion.

Although the similarity in the asymmetry index (9.8%) for hip flexion is close to 10% and suggests that there is no asymmetry between limbs, the normalized hip flexor peak torque values were higher in the preferred compared to the non-preferred limb at 60°·s^{-1}, which suggests that the 10% limit for the asymmetry index is not necessarily a fixed value, and even lower than 10% values may be related to some kind of asymmetry. This apparent torque asymmetry seems to be related to the need for the non-preferred limb to act as the support limb and stabilize hip motion, being less exposed to stimuli variations during dynamic contractions.

Results found for the lateral preference test and those in the literature suggest that preference is intimately related to task performance.[28,29] During many sports practices the non-preferred limb, with respect to the hip-trunk muscle contractions, works naturally in postural stabilization, whereas the preferred limb acts more in the development of forces for the dynamic act of technical gestures, thereby diminishing its role in balance control.[30]

The working versus supporting leg is dependent on the movement being executed and also driven by split preference and rotational preference, which are correlated to, but not identical to footedness. The gymnast will use her left leg (NPREF) for support when the right leg (PREF) needs to be to the side or forwards to perform an element that requires it. But she will use her right leg (NPREF) for support when the left leg (NPREF) needs to be behind her. The demands on the supporting leg, whether preferred or non-preferred, are light co-contraction of hip, knee, and ankle musculature to maintain position. But even in situations in which the non-preferred leg is the supporting leg, the muscular demands on the leg are quite different than when the preferred leg acts as the supporting leg. Agreeing with this supposition, Golomer et al[31] found no difference in lateral preference and the choice of the supporting foot in untrained girls (mean age = 9.5 years) and professional dance students (mean age = 11.9). No relationship between foot most often used as support for turns and balance and preferred foot was found in either group. Golomer et al[31] showed that the choice of a supporting leg for turning might exploit some biomechanical properties that facilitate the movement, so the choice is not linked to laterality but to the movement type.

Despite the fact that Waterloo Questionnaire revealed the right lower limb as the preferred limb, the authors believe that, for RG, the lateral preference designation is probably not appropriate, since this changes depends on the task performed, especially in three situations: leaps, balances, and turns. This characteristic makes identifying leg or side preference somewhat difficult.[32]

Another factor that should be considered is task difficulty and time spent on training the tasks. As turns and leaps are technically more difficult to perform, these skills will be practiced more than balance-related tasks during training sessions. Turning in single-leg stance requires a great amount of muscle co-contraction at the hip, knee, and ankle in order to maintain body position and is considerably more difficult than balancing statically. Time spent on the supporting leg is considerably greater during turns than during leaps or balance tasks. During a given choreographed routine the gymnast will also execute more turns and leaps than balance related tasks.

It is important to remember that RG is strongly based on classical ballet technique, and many ballet dancers claim to be able to sense differences between their legs in terms of strength, flexibility, and functionality. However, Mertz and Docherty[33] showed that dancers' opinions of their leg characteristics did not correlate with their actual ability. RG athletes that have a right lower limb preference also use the left lower limb for support, which plays an important role in several elements of RG. Therefore, RG athletes may not necessarily display higher force, flexibility or other qualities in one limb due to these different roles during sports practice.

Wu et al[34] examined high performance RG athletes (mean age = 18 years) and found that the knee flexors and extensors of the left (non-preferred) limb were stronger than those of the right (preferred) limb at low and medium angular velocities. Different results were found by Lanshammar and Ribom,[35] who suggested that, in any sports practice, a considerable asymmetry exists for the force relation between hamstrings and quadriceps in young adult females, with the hamstrings being weaker on the preferred limb and the quadriceps weaker on the non-preferred limb. The authors took into account the sports practice and not the specific physical training of the activity. Therefore, it appears that RG training may have promoted strength equilibrium between the preferred and non-preferred limbs of the studied athletes in the current research.

According to results of the regression test, increased knee flexor range of motion positively influenced the torque results. These findings suggest that longer muscles are related to the torque produced at higher angular velocities, as apparently more that 50% of the knee extensor torque at $240^\circ \cdot s^{-1}$ was influenced by the total joint range of motion.

Although a large part of the observed asymmetries are related to sports practice, the specific exercises and gestures that are performed during RG in a combination of compensatory movements were minimized by the way the athlete was fixed to the isokinetic dynamometer. It is possible that these athletes depend on a series of multi-joint compensations for the execution of specific movements, and single joint torque measurements do not accurately represent their sport specific strength. These compensations might affect the neuromuscular efficiency throughout the whole kinetic chain and could be caused by muscle imbalances.[36]

The limited sample size resulted in large variance in the data and a consequent reduction in statistical power. Although RG training has common elements among the different teams, some characteristics seem difficult to compare due to the specificity of training routines. This makes comparisons between teams and individuals difficult and does not allow for extrapolation of the observed results. Another fact that should be considered in future studies is the inclusion of athletes with left lower limb preference in order to determine whether inter-limb differences are indeed the result of preference, but, of note, the authors were unable to find a left lower limb preference RG athlete available to participate in the study. Nevertheless, the results of the present study show evidence of few lower limb asymmetries in high performance RG athletes of a Brazilian team, and might serve as a reference point for future comparisons with other high performance teams.

CONCLUSIONS

The results of the current study indicate that lateral preference and RG training had an effect on the thigh girth and torque production in some muscles, while having no effect on the lower leg girth. The preferred limb showed larger thigh girth and anatomical cross-sectional area, higher ankle dorsiflexor range of motion, higher hip flexor torque at $60^\circ \cdot s^{-1}$ and higher plantarflexor torque at $180^\circ \cdot s^{-1}$ compared to the non-preferred limb. Further research that controls for other neuromuscular and structural variables will allow for better understanding of the reasons for the differences found in this research.

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